Underwater Sound Measurements

Understanding Underwater Sound Measurements: Sound volume is expressed in decibels (dB), which provide a measure of the intensity of sound. Decibels do *not* form a linear progression, meaning that 200 dB would be twice as loud as 100 dB. Instead, they are based on a logarithmic scale something like the Richter scale for earthquakes. A doubling in sound intensity is indicated by a 3 dB increase, regardless of the level of the original sound. For example, a dB level of 63 is twice as loud as 60 dB and a dB level of 180 is twice as loud as 177 dB. Every 10 dB increase represents a tenfold increase in intensity, thus 180 dB is ten times as loud as 170 dB.

For decibels to have relevance, they must be referenced to pressure. Sound waves generate a momentary overpressure, followed by underpressure, then a return to ambient pressure. Substantial changes in pressure can cause damage. The amount of pressure (and the length of time an animal is exposed to it) determines whether the animal might be harassed, injured or killed by an underwater sound. This is why pressure is so important in assessing potential impacts of underwater sounds.

Equating an underwater sound to the sound of a rock band or jet engine (both of which are scarce underwater) has no relevance without a reference to pressure. As an analogy, a loud sound in outer space has few molecules to push against, hence it exerts little pressure. By contrast, a loud sound at sea level has many more molecules to push against, so it generates more pressure. A similar contrast can be drawn between loud airborne sounds and underwater sounds.

A micropascal (µPa) is a measurement of pressure commonly applied to underwater sound. (One pascal is equal to the pressure exerted by one newton over one square meter. One micropascal equals one-millionth of this.) Underwater sounds are usually referenced to 1µPa, whereas airborne sounds are usually referenced to 20 µPa. Thus, underwater sound measurements are expressed as X dB re 1µPa, which represents the peak pressure of an underwater sound. Peak pressure can also be expressed in pounds per square inch (psi) above ambient pressure.

Underwater sound pressure measurements can also be expressed as X dB re 1 µPa-m, which represents the theoretical sound pressure level within one meter of the source. This is often referred to as the source level. The reference distance of one meter is included so that a measured or modeled level at a given distance can be compared to the level at the source itself.

Another measurement expresses the average peak pressure over the duration of the sound pulse, expressed as X dB re 1 µPa-rms (root mean square). Such measurements are sometimes applied to the protection of marine mammals during projects involving geophysical airguns, which fire regular bursts of sound.

Understanding the maximum amount of sound energy that can be received by a marine mammal without injury is very important. Energy is proportional to the time integral of the pressure, expressed in micropascals squared: X dB re 1µPa_-sec. This type of measurement is now applied to projects involving the use of underwater explosives.

Sound Speeds through Different Media: Sound travels about five times faster underwater than it does in air (about 1500 meters a second compared to 300 meters a second). Sound travels even faster through rock (some 5000 meters a second). Understanding the speed of sound through different media is important. For example, sea lions hauled out on a buoy might react to the airborne sound of an explosion and leap into the water, but the underwater sound wave will have already passed the sea lions. Sound speed through different media is also important in modeling estimates of sound pressure levels. These estimates are used in projecting wildlife safety zones.

Application of measurements for establishing wildlife safety zones: NOAA Fisheries (formerly National Marine Fisheries Service or NMFS), which has jurisdiction over most marine mammals and all sea turtles in the region, has not set any standard measurement for safe sound levels. This is because of our limited knowledge of the true hearing thresholds of such animals and their sensitivity to various sound levels, frequencies and durations (please see Hearing Thresholds of Marine Mammals, Sea Turtles and Seabirds, which follows). Nonetheless, various sound level measurements have been accepted by the regulatory agencies for establishing the threshold of sound at which harassment or injury to marine mammals and sea turtles may occur. New levels may be adopted in the near future. The levels that have been used in past projects and their applications are presented in the table below.

Threshold Levels

Threshold Level	Representing	Application(s)	Organisms
180 dB re 1 μPa	Peak pressure	Explosives	Marine mammals
182 dB re 1 μPa_ - s	Energy	Explosives	Marine mammals
12 psi – ms	Max. pressure	Explosives	Marine mammals
30 psi – ms	Max. pressure	Explosives	Birds on surface
160 dB re 1 μPa - rms	Average peak pressure	Geophysical airguns	Baleen and sperm whales only
180 dB re 1 μPa – rms	Average peak pressure	Geophysical airguns	Pinnipeds and small cetaceans

Sound Frequencies: Understanding the frequencies of sounds produced from human activities is helpful in assessing potential impacts to marine wildlife. Various species of marine mammals hear sounds in given ranges of frequencies. When sounds produced by humans fall within their range of hearing, a potential for harassment exists. If a sound is loud enough, even though it is outside the hearing frequency range, it sometimes can still be detected by a marine mammal and can even cause injury if it is extremely loud.

Sound frequency can be measured in hertz (Hz) and kilohertz (kHz). Hertz is a measure of sound frequency in cycles per second (one hertz equals one cycle per second). The lower the number, the lower the sound. One kilohertz equals 1000 hertz. To relate these frequencies with hearing, consider that humans with very good hearing generally can hear sounds as low as 20 Hz and as high as 20,000 Hz (20 kilohertz).

Understanding the frequency spectrum of human-generated underwater sounds is also very important is assessing potential impacts to marine mammals. High frequency sounds rapidly attenuate with distance. Very low frequency sounds can travel great distances, however. Thus, high frequency sonar, such as fish finders, have comparatively limited ranges and relatively little intensity, so they will not harm marine mammals. Low frequency sonars are designed to send signals over a wide swath of ocean. To accomplish this, a high-decibel, low frequency signal is employed. Low frequency sonar can injure or kill marine mammals.

Hearing Thresholds of Marine Mammals, Sea Turtles and Seabirds: The collective knowledge of marine mammal hearing and sound detection capabilities is very limited. Much of our knowledge of the hearing frequencies of marine mammals is based on the frequency range at which they vocalize rather than the range at which they actually hear. But animals, like humans, can hear sounds that are higher and lower than the frequencies at which they vocalize. For example, how many of us can reach all the notes in “the Star-Spangled Banner?” Yet all of us can hear the notes. Also, many recordings made of marine mammal vocalizations do not cover the full range of frequencies for their vocalizations because most recording equipment is designed to accommodate the human range of hearing.

A presumption is sometimes made that an animal cannot be harassed by a sound of a given frequency if it cannot hear in that frequency. Animals can sometimes detect sounds or even be injured by sounds that are beyond their hearing thresholds, however. Hearing frequency ranges for some species of marine mammals and sea turtles found in this region are presented on the table on the next page.

Frequency Ranges for Selected Species

Taxa	*Common Name*	*Genus/Species*	*Frequency Range*
Odontocetes	Short-beaked common dolphin	*Delphinus delphis*	500 Hz to 67 kHz
	Short-finned pilot whale	*Globicephala macrorhynchus*	500 Hz to 20 kHz
	Risso's dolphin	*Grampus griseus*	80 Hz to 100 kHz
	Pacific white-sided dolphin	*Lagenoryhnchus obliquidens*	2 kHz to 80 kHz
	Northern right whale dolphin	*Lissodelphis borealis*	1 kHz to 40 kHz
	Killer whale	*Orcinus orca*	500 Hz to 120 kHz
	False killer whale	*Pseudorca crassidens*	1.1 kHz to130 kHz
	Spotted dolphin	*Stenella attenuata*	3.1 kHz to21.4kHz
	Striped dolphin	*Stenella coeruleoalba*	6 kHz to 24 kHz
	Spinner dolphin	*Stenella longirostris*	1 kHz to 65 kHz
	Bottlenose dolphin	*Tursiops truncatus*	40 Hz to 150 kHz
	Hubbs' beaked whale	*Mesoplodon carlhubbsi*	300 Hz to 80 kHz
	Blainville's beaked whale	*Mesoplodon densirostris*	1 kHz to 6 kHz
	Pygmy sperm whale	*Kogia breviceps*	60 kHz to 200 kHz
	Sperm Whale	*Physeter macrocephalus*	100 Hz to 30 kHz
	Harbor porpoise	*Phocoena phocoena*	1 kHz to 150 kHz
	Dall's porpoise	*Phocoenoides dalli*	40 Hz to 149 kHz
Mysticetes	Gray whale	*Eschrichtius robustus*	20 Hz to 2 kHz
	Minke whale	*Balaenoptera acutorostrata*	60 Hz to 20 kHz
	Sei whale	*Balaenoptera borealis*	1.5 kHz to 3.5 kHz
	Bryde's whale	*Balaenoptera edeni*	70 Hz to 950 Hz
	Blue whale	*Balaenoptera musculus*	12 Hz to 31 kHz
	Fin whale	*Balaenoptera physalus*	14 Hz to 28 kHz
	Humpback whale	*Megaptera novaeangliae*	20 Hz to 10 kHz
Pinnipeds	Northern fur seal	*Callorhinus ursinus*	4 kHz to 28 kHz
	California sea lion	*Zalophus californianus c.*	100 Hz to 60 kHz
	Northern elephant seal	*Mirounga angustirostris*	200 Hz to 2.5 kHz
	Harbor seal	*Phoca vitulina richardsi*	100 Hz to 180 kHz
Mustelids	Sea otter	*Enhydra lutris nereis*	3 kHz to 5 kHz
Testudines	Cheloniid sea turtles	N/A	60 Hz to 800 Hz
	Loggerhead sea turtle	*Caretta caretta*	250 Hz to 1000 Hz

Note: Most of the frequency ranges listed above represent the range of frequencies in which these species vocalize. In a few cases, frequency response ranges are known and are presented. In all cases, the most extreme ranges known at low and high frequencies are noted.

Sources: Au *et al.* 2000; Lenhardt 1994; Moein *et al.* 1994; Richardson *et al.* 1995; Ridgway *et al.* 1997.